IN-HOUSE RESEARCH PROGRAM

CHAPTER 3

The National Science Foundation charged the National High Magnetic Field Laboratory (NHMFL) with developing an in-house research program that *utilizes* the NHMFL facilities to carry out high quality research at the forefront of science and engineering; and *advances* the laboratory's facilities and its scientific and technical capabilities.

To this end, the NHMFL established in 1996 an in-house research program that stimulates magnet and facility development and provides intellectual leadership for experimental and theoretical research in magnetic materials and phenomena. The NHMFL In-House Research Program (IHRP) seeks to achieve these objectives by funding research projects of normally one- to two-year duration in the following categories:

- small, seeded collaborations between internal and/or external investigators that utilize their complementary expertise;
- bold but risky efforts that hold significant potential to extend the range and type of experiments; and
- initial seed support for new faculty and research staff, targeted to magnet laboratory enhancements.

The IHRP strongly encourages collaboration across host-institutional boundaries; between internal and external investigators in academia, national laboratories, and industry; and interaction between theory and experiment. Some projects are also supported in order to drive new or unique research, that is, to serve as seed money to develop initial data leading to external funding of a larger program. In accordance with NSF policies, the NHMFL cannot fund clinical studies.

The IHRP is now four years old. Four solicitations have been completed with a total of 168 proposals being submitted for internal review. Of the 168 proposals, 92 were sent to external review, and 39 were funded (23% of the total number of submitted proposals). The results from the funded projects are beginning to materialize and are reported in Chapter 1 (Research Reports) of this publication. IHRP-funded projects are noted in this report volume with the following symbol: IHRP.

1999 Solicitation and Awards

Thirty-three proposals were received for the fourth IHRP solicitation. The proposals spanned a very significant intellectual breadth, consistent with the intentions of the program, and the balance among research disciplines and/or techniques noted in the first solicitation continued:

Magnetic Resonance	10 proposals received
Condensed Matter Physics	15 proposals received
Materials Science/Engineering	8 proposals received

Of the 33 proposals received, the internal review committee recommended that 22 proposals undergo external peer-review. Two external reviews were sought for each proposal. Final funding decisions were determined by the NHMFL Chief Scientist J. Robert Schrieffer. The awards were announced in August, 1999. Tables 1 and 2 summarize the results of the solicitation, and the research results of these projects will be presented in future annual reports.

Table 1. 1999 IHRP awards by category.

Research Area	Number of Proposals Submitted	Number of Projects Funded
Magnetic Resonance	10	3
Condensed Matter Physics	15	3
Materials Science & Engineering	8	1
TOTAL	**33**	**7**

Table 2. 1999 IHRP funded projects.

Principal Investigator	NHMFL Institution	Project Title	Project Duration
Alexander Angerhofer	UF Chemistry	*Ultrafast switches for pulsed sub-mm radiation*	2 years
James Brooks	FSU Physics	*Millimeter wave spectroscopy in nano-magnets and low dimensional materials*	2 years
Gang Cao	NHMFL	*Common trends in manganites and ruthenates*	2 years
Chris Hammel	LANL	*NMR studies of field-induced phases in anisotropic correlated electron systems*	2 years
Timothy Logan	FSU Chemistry	*Triple resonance microcoils for high field NMR*	2 years
Mark Meisel	UF Physics	*Low gravity plant experiments using high magnetic field gradient levitation*	2 years
Antoinette Taylor	LANL	*Terahertz spectroscopy at high magnetic fields*	2 years

Below are the project summaries of the 1999 grant awards.

Ultrafast Switches for Pulsed Sub-mm Radiation
PI: **Alexander Angerhofer** (UF)
Funding: $139,895 over two years

This proposal addresses one of the scientific and technological barriers for the application of pulsed high field EPR at frequencies above 150 GHz, *i.e.*, the lack of fast switches. While the primary concern of this project is to facilitate pulsed excitation of electron spins at ultra-high fields for the benefit of applying spin-echo spectroscopic techniques to problems in photobiology and photochemistry, the design of a suitable switch would have much broader ramifications in scientific and technological applications. The design goal is a broadband switch operating between 100 and 700 GHz with switching times of the order of 100 p5. Furthermore, it is planned to set up a switching network that would allow variable pulse lengths and variable pulse delays in order to take full advantage of today's advanced EPR pulse techniques.

The success of this project depends strongly on the identification and harnessing of new materials that can be switched very quickly between the conductive and isolating state for the given frequency range. One such material is the organic conductor $Cu(DCNQI)_2$ (DCNQI = Dicyanoquinonediimine), which has shown very fast light-induced switching of DC conductivity over up to eight orders of magnitude. The material can be formed in either single crystalline form or as thin films and shows transition times of the order of 100 ps.

The current project constitutes a feasibility study in which a number of promising DCNQI radical ion salts will be prepared in crystalline and thin film form and their conductivity and switching behavior studied over a wide frequency range (up to 800 GHz). A prototype-switching network will be built and tested.

Millimeter Wave Spectroscopy in Nano-Magnets and Low Dimensional Materials
PI: **James Brooks** (FSU)
Funding: $122,103 over two years

Millimeter (mm) wave conductivity and spin resonance measurements provide fundamental information for understanding the electronic and magnetic behavior of materials that oftentimes exhibit their most important properties at low temperatures and high magnetic fields. Properties such as quantum tunneling of magnetization (QTM), non-Fermi liquid behavior in correlated metals, and vortex lattice dynamics in highly anisotropic superconductors are but a few examples. Although research in these areas is extensive, recent progress in phase sensitive detection, tuneability of sources, and the application of high-Q cavity resonators has given this field a new dimension, especially in the regime of high magnetic fields. Enhancement of existing capabilities at the NHMFL in the area of mm wave spectroscopy and complex conductivity measurements in novel systems, including low-dimensional materials, is proposed. The central instrumentation is a facility based on a Millimeter Wave Vector Network Analyzer (MVNA) that Dr. N. Biskup is operating in the 8 to 150 GHz range with the PIs, and also with outside users. Facilities enhancement will include:

(1) Low temperature. We propose to build a high Q cavity resonator probe that will go to helium-3 temperatures in fields up to 45 T.
(2) Angular dependence. We propose to build a probe that will allow access to the 14 T Oxford, radial access superconducting magnet.
(3) Long-term access to 20 T magnetic fields. We propose to make probes long enough to utilize the 20 T superconducting magnet "SCM-2" in the mK Facility.

The facilities enhancement will be driven by the proposed scientific program of the PIs and outside collaborators and users. The proposed facility will enable us to carry out new measurements in two distinctly different but related areas of our basic research programs: (a) synthesis and characterization of molecular nano-magnets with very high electronic spin ground states and that exhibit the QTM phenomenon, (e.g., $Mn_{12}O_{12}$-acetate and its analogs), and (b) understanding the behavior of novel transport and superconducting mechanisms in organic metals/superconductors. The mm-wave data will be complemented with DC (cantilever) magnetization measurements as well as other conventional measurements in a well-coordinated fashion. It is expected that the successful completion of the proposed undertaking will constitute a significant enhancement of PIs' current and future research initiatives and will add an important new experimental capability at NHMFL.

The proposed work is interdisciplinary, involving two PIs with complementary expertise: Brooks in Physics (measurements in high fields and low-dimensional materials) and Dalal in Chemistry (materials synthesis and EPR spectroscopy).

Other important collaborator-users include G. Gruner (UCLA), R. Lewis (Univ. Wollongong), J. Singleton (Oxford Univ.), J. Perenboom (Univ. Nijmegen), and G. Cao (NHMFL). Attention will be given to include students in the research as part of the ongoing educational outreach programs at the NHMFL.

Common Trends in Manganites and Ruthenates
PI: **Gang Cao** (NHMFL)
Funding: $153,650 over two years

A large body of experimental work has shown that a family of transition-metal-oxide (TMO) compounds, the manganites, have a rich phase diagram that includes ferromagnetic and antiferromagnetic phases, metal-insulator transitions, and tendencies to form charge-inhomogeneous states. Theoretical studies of these compounds have revealed unexpected tendencies to phase separation between hole-rich and hole-poor regions that may contribute to its colossal magnetoresistant effects. By comparison, the study of another important TMO family, the ruthenates, is at its early stages although it has already attracted considerable attention. Magnetic and transport regimes have been found experimentally suggesting some intriguing properties similar to those of the manganites, but more work is needed to complete the task. Here, the previous experience gained in manganites, both on experiments and theory, is proposed to be applied to the analysis of ruthenates. Preliminary work for the proposal has already identified any common trends between the two families of compounds, notably a competition between ferromagnetic and antiferromagnetic states, which may lead to phase segregated regions, as well as the existence of a large magnetoresistant effect in the ruthenates. A comprehensive study of these characteristics is here proposed. The work includes the development and use of equipment for high pressure and high magnetic field measurements (above 30 T) at the NHMFL, and the application of computational tools for the theoretical calculations.

NMR Studies of Field-Induced Phases in Anisotropic Correlated Electron Systems
PI: **Chris Hammel** (LANL)
Funding: $144,400 over two years

We propose to perform a combination of NMR experiments at high magnetic fields on organic and inorganic conductors in which the low-field phases are, or could be, different from what is observed at high fields. The materials to be studied are representative of correlated electron systems near to phase transitions between different ground states, including the Spin-Peierls compounds $(TMTTF)_2PF_6$, the organic superconductors $(TMTTF)_2PF_6$, and $(TMTSF)_2C10_4$, and the high-temperature superconductor $La_{2-x}Sr_xCuO_4$. Generally, we will use NMR signatures as appropriate to characterize the normal states and high field ground states, including but not restricted to relaxation rates, paramagnetic shifts, and static line-broadening from the development of local fields as for an antiferromagnet. Motivations for the experiments come from recent results of other experiments, including NMR and transport, as well as theoretical predictions. The experiments are to be carried out under conditions that are unusual as appropriate, namely at high fields up to 30 T and temperatures at least as low as .35 to .4 K, and under pressure in cells precision-alignable to the field. All of the work described takes advantage of the special facilities offered by the NHMFL. The subjects of our experiments were chosen both for their level of interest in the condensed matter physics community and to take advantage of the individual experiences of the PIs.

Over the course of the two-year grant, we plan experimental runs at both the Los Alamos 20 T superconducting magnet facility and the resistive magnets of cell 7 and cell 8 at Tallahassee. The hardware development will be performed in part by a graduate student working at both LANL and UCLA in consultation with the PIs. The requested funding asks for partial support of the graduate student, design and fabrication costs required in preparation for some of the experiments, and support for expenditures directly and indirectly related to actually performing the experiments.

Triple Resonance Microcoils for High Field NMR
PI: **Timothy Logan** (FSU)
Funding: $90,816 over two years

In this proposal, we present designs for novel triple-resonance microcoils for use in high resolution NMR spectroscopy of biological molecules at high magnetic fields. Because of their small sample volumes, microcoils have significantly higher signal-to-noise ratios (SNR) for a given volume than conventional NMR probes. Microcoils have improved the limits of detection of organic and biological molecules to the picomole level. In the proposed research, we will design and build microcoils having three independent rf channels that are tuned to ^{1}H, ^{13}C, and ^{15}N resonance frequencies. Circuitry will also be included to provide a field-frequency lock and pulsed field gradient coils. Therefore, these microcoils will be capable of performing a wide range of modern, multifrequency, multidimensional NMR experiments used to determine the structures of biological macromolecules.

The initial phase of the project will be to optimize the design and performance of these microcoils on the 720 MHz NMR spectrometer at the NHMFL. In the second phase of the proposed research, we will use the experience gained on the 720 MHz instrument to develop a triple resonance microcoil for use on the Magnex 20 T magnet at the NHMFL. The low homogeneity of this magnet precludes high resolution applications using conventional sample geometries, although the magnetic field is sufficiently homogeneous over the small sample volumes in microcoils (-1μ(L) to support high resolution studies.

The successful development of functional triple resonance microcoils for the Magnex magnet would result in the highest field superconducting NMR system in the world, and would provide a unique resource both for internal and external NMR spectroscopists.

Low Gravity Plant Experiments Using High Magnetic Field Gradient Levitation
PI: **Mark Meisel** (UF)
Funding: $96,482 over two years

A number of significant problems must be solved before humans will be able to spend long periods of time in space. One major issue is the establishment of a renewable food supply since, to date, plants cultivated in low gravity possess reduced growth characteristics. The proposed research addresses this issue through the study of gene regulation in plants growing in a low gravity environment generated by high magnetic field levitation. More specifically, arabidopsis *(Arabidopsis thaliana)* will be used as a model system Arabidopsis is presently being studied extensively at the University of Florida as part of a space biology program currently manifested as a mid-deck payload on Space Shuttle Mission STS-93, likely to fly in early 1999. Furthermore, preliminary reports by other researchers have indicated that the growth of arabidopsis may not be significantly perturbed by the presence of the high magnetic fields (21 T) and gradients (field-gradient product   1800 T2 m-1) required for levitation, and the NHMFL in Tallahassee is well suited for providing these conditions with long-time stability. In fact, preliminary magnetic levitation experiments, spanning 2.3 hours, have been performed at the NHMFL. The results qualitatively suggest that the arabidopsis plants were differentially stressed by the high magnetic field and low gravity environments. In other words, low gravity environmental effects may be induced by magnetic levitation, albeit on a "background" response generated by the strong magnetic field. Additional experiments are proposed for a duration of up to 8 hours, which represents a significant fraction of the growth of the seedlings, which reach maturity in about 3 weeks. Quantitative determinations of the reporter gene stress response will be performed by biochemical assays. These microscopic investigations are needed to determine the molecular consequences of levitation and high magnetic fields on plant growth and development. Ideally, the magnetic field response "background" should be nullified, if possible, thereby leaving the low gravity stress as the sole environmental variable. In addition, the origins of the magnetic effects need to be understood if high magnetic field ($B \sim 20$ T) MRI is going to be used to image *in vivo* gene regulation, an application proposed for the new generation of GHz NMR facilities.

Terahertz Spectroscopy at High Magnetic Fields
PI: **Antoinette Taylor** (LANL)
Funding: $185,500 over two years

The goal of this project is to establish time-domain terahertz (THz) spectroscopy as a diagnostic capability on the 60 T Long-Pulse Magnet at the NHMFL at Los Alamos. This new capability will enable the measurement of the dynamic conductivity in materials in the frequency range from 5 to 80 cm^{-1}. Once this diagnostic is implemented on the 60 T magnet, a series of experiments will be performed to measure the dynamic conductivity in correlated electronic materials at high fields. In particular, the dynamic conductivity in a Kondo insulator ($Ce_3Bi_4Pt_3$) will be determined as its gap is diminished and ultimately destroyed through the application of sufficiently high magnetic field. Also, measurements of the temperature dependence of the dynamic conductivity in high temperature superconductors such as $La_{2-x}Sr_xCuO_4$ will be performed in sufficiently high fields that the superconducting transition has been suppressed.

A summary of the steps leading up to the final implementation of a time-domain THz spectrometer in the 60 T magnet is as follows:

1. Development of a fiber-coupled THz spectrometer for easy use inside the magnet's bore. It will be necessary to miniaturize the THz antennas and determine the best process for bonding them to single-mode optical fibers.
2. Characterization of the system bandwidth and signal-to-noise in a mock-up of the experimental apparatus in zero field on an optical table.
3. Investigation of system performance and implementation of initial experiments on high-T_c materials in the 20 T DC magnet at NHMFL-LANL.
4. Determination the optimum method for fast-scanning and rapid data collection. Optimization of system performance in a 100 ms time span.
5. Implementation and optimization of THz spectroscopy on 60 T Long-Pulse magnet, in particular, minimization of noise pickup from the magnet.
6. Implementation of a series of experiments to measure the dynamic conductivity in correlated electronic materials at high fields

Implementation of time-domain terahertz spectroscopy at the NHMFL represents a significant addition to the current suite of diagnostics. This new capability will enable the measurement of the dynamic conductivity in materials in the frequency range from 5 to 80 cm^{-1} and is therefore well suited to probe low-lying excitations in a variety of condensed matter systems. It bridges and hence complements current in-house capabilities for transport and optical measurements.

2000 IHRP Solicitation

The fifth IHRP proposal solicitation was released in January, 2000, with a pre-proposal deadline of March 13, 2000. Awards will be announced in the summer of 2000.